Modeling the interannual variability of hypoxia (1985–Present)

CHAMP site review

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Introduction

We have been conducting simulations of the historical period, 1985–Present, with various model configurations. They use the same hydrological (Phase 6) and meteorological forcing (ERA5). (Additional experiments with DLEM are planned.)

WQMP observations are used to evaluate the model configurations, and determine the improvement associated with each modification.

This intercomparison can teach us something about CB's hypoxia itself.

Outline:

1. Model configurations
2. Model-data comparisons
3. Interannual variability of hypoxia
4. Future work

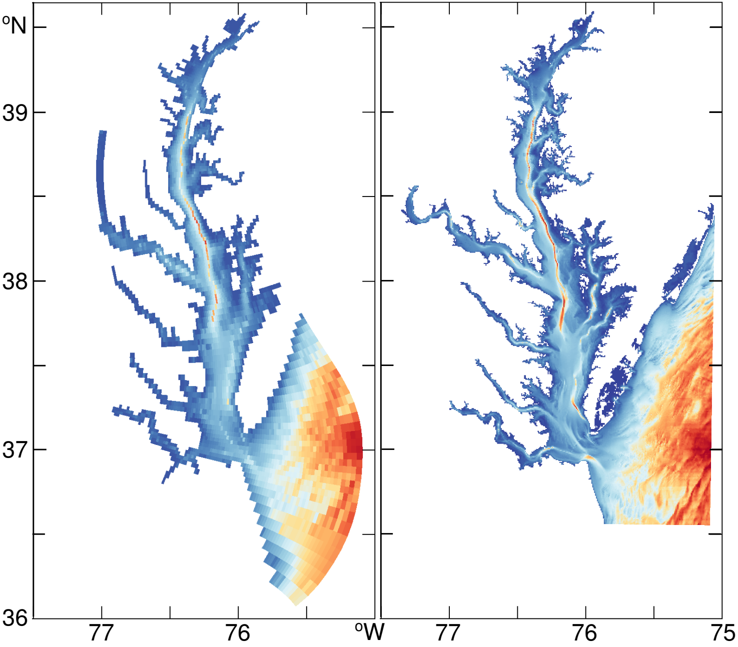
Two model configurations:

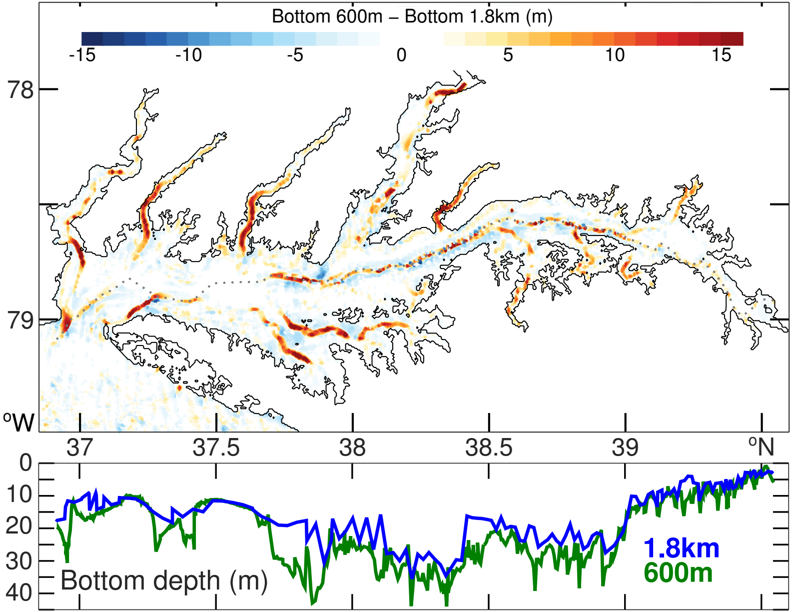
~**1.8 km** grid versus **600 m** grid.

Key benefits of 600 m grid:

More realistic coastlines,
Little to no bathymetric smoothing required,
More realistic geometry for the deep channel (where hypoxia is prevalent) and tributaries.

Also, represents inundation at the coastlines and includes a sediment model;
(P limitation is under way.)



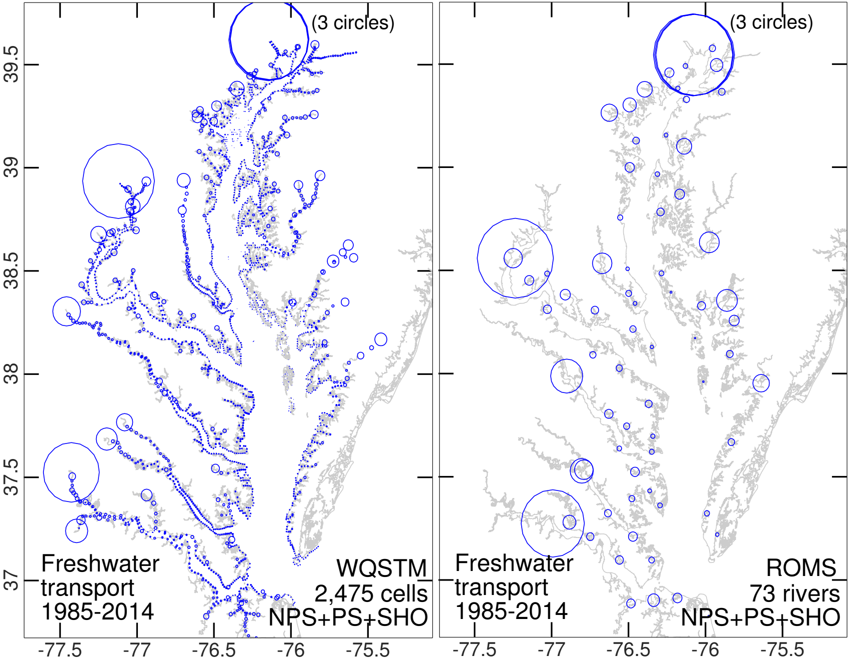


Area of the deep channel:

$Area_{600m}$ = 815.4 km^2
$Area_{1.8km}$ = 848.7 km^2
(difference of 4%).

Volume below 13 m depth (∼pycnocline):
$Volume_{600m}$ = 4.5 km^3
$Volume_{1.8km}$ = 3.7 km^3

The 600 m grid can accommodate ∼ 20% more hypoxic water than the 1.8 km grid in the same area.

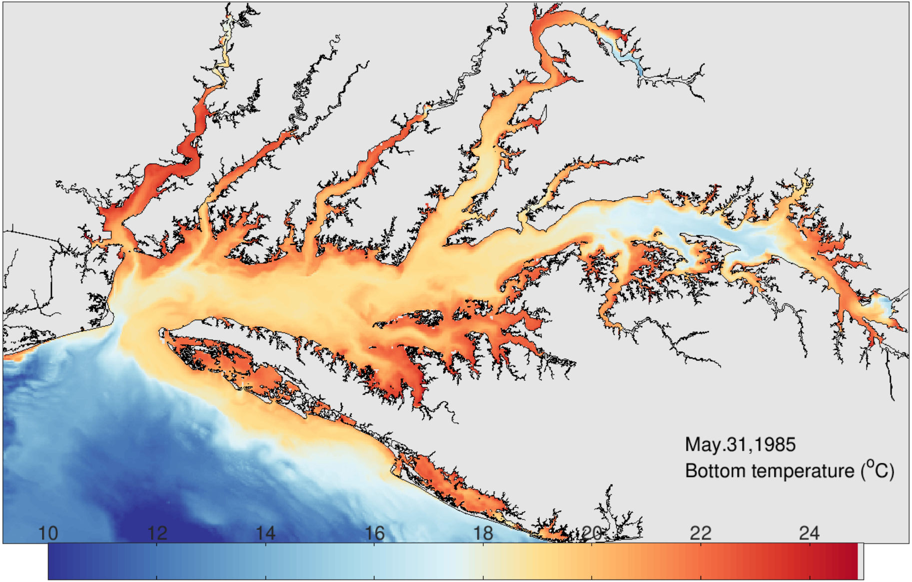


600 m grid also features improved terrestrial fluxes.

2,475 input points of Phase 6 aggregated into 73 ‘rivers’.

1.8 km grid: 10 rivers.

One last improvement: 600 m grid allows for a “biology-physics interaction” (Kim et al. 2020).



Video of 600m grid in action:

Model-data comparisons

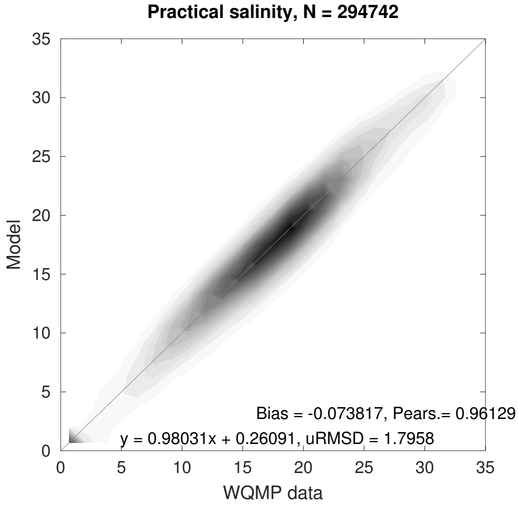
Salinity bias

These slides compare our *latest historical run* against the WQMP data. Model and data are matched in time/location/depth and statistics are computed. Period: 1985–2014.

Overall bias is very small, -0.07.
Suggests estuarine circulation is well reproduced.

Bias has improved by 1.2 units with 600m grid.

Most apparent bias is in Dec.-Jan., at surface, near the mouth of the Bay.



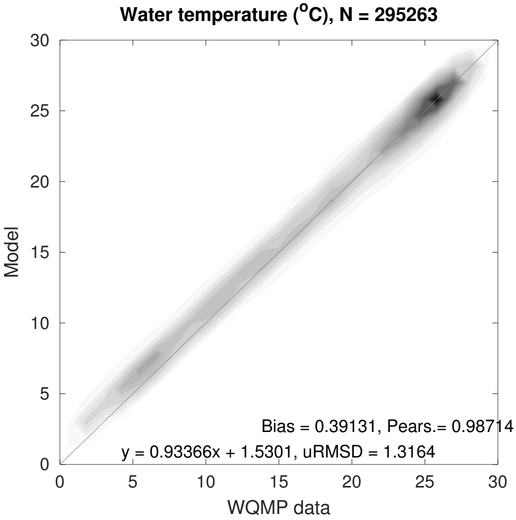
Temperature bias

Model is most accurate in summer (during hypoxia). Warm bias of $\approx +1^\circ$C during winter months.

Bias has improved by 0.3° C with 600m grid.

The warm bias is concentrated in the first decade, 1985–1995, and in Dec–Jan.

During this period, the warm bias is apparent at surface throughout the Bay; atmospheric forcing (ERA5) is likely to blame.

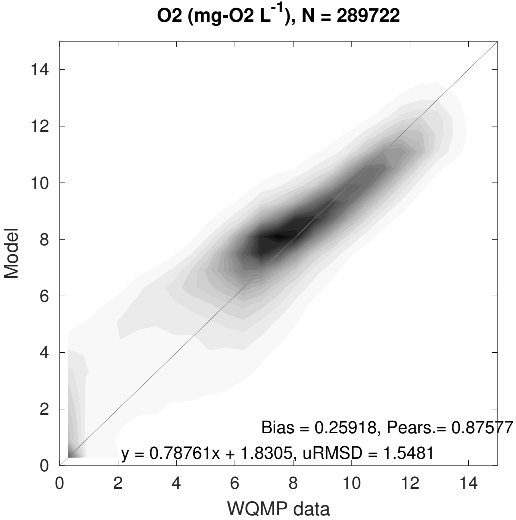


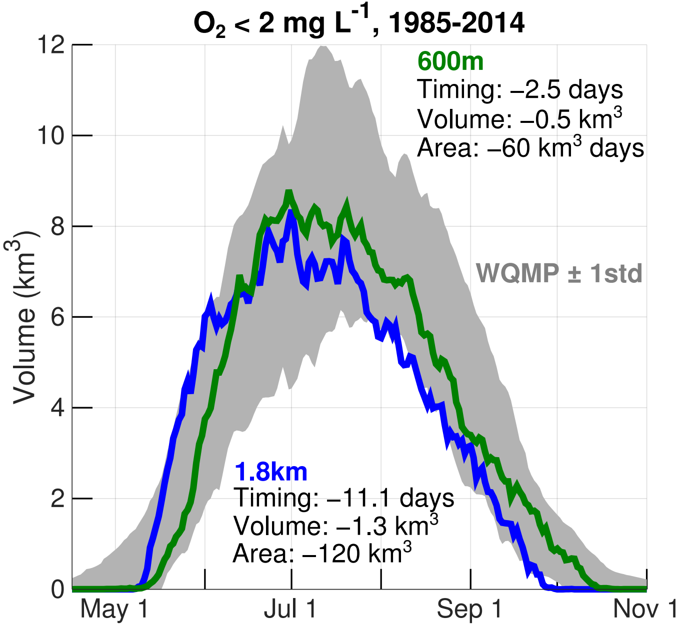
Dissolved O_2 bias

Overall, small positive bias of +0.26 mg L^{-1}.

Bias is comparable in the two model configurations,
was slightly lower in 1.8km (by 0.05 mg L^{-1}).
Other statistics show negligible change.

The positive bias is concentrated in Jul–Aug,
at the surface in the upper Bay,
and at the bottom in the lower Bay.





What about hypoxia?

Three metrics:

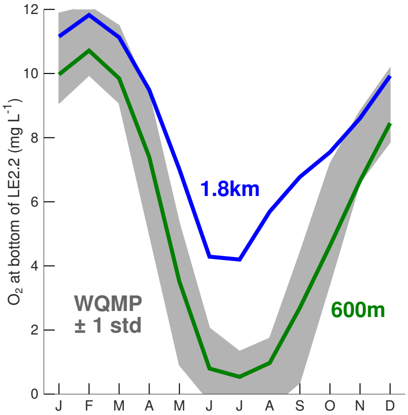
- Timing of peak hypoxia,
- Volume at peak hypoxia.
- Area under the curve.

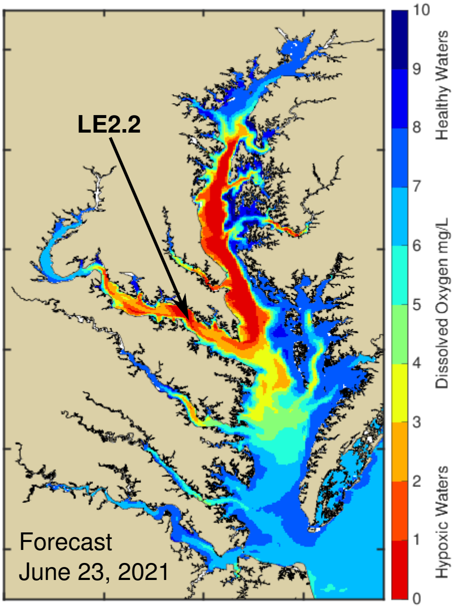
WQMP computed as in Bever et al. 2013.

600m grid shows a major improvement in all three metrics.

600m also shows hypoxia inside certain tributaries →

WQMP data of 1985–2014 confirm that this prediction is correct and is an improvement over the **1.8km**:





Interannual variability of hypoxic volume

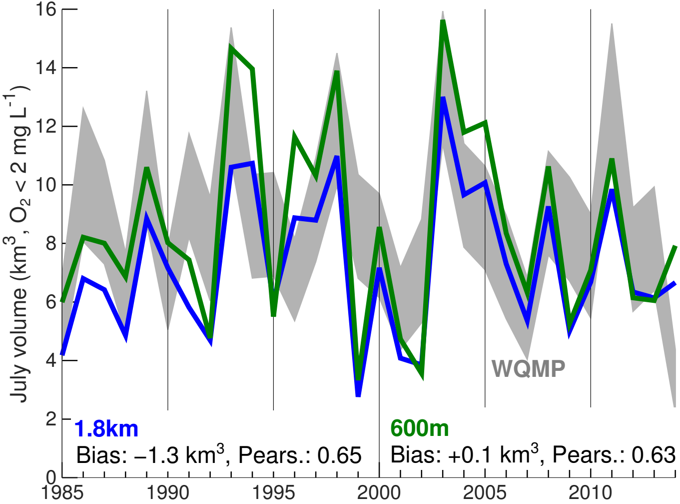
Two metrics:

- **July hypoxic volume**(*year*), in km^3
- **annual hypoxic volume**(*year*), in $km^3 \times$ days

July volume is well constrained by WQMP observations,
useful to evaluate which of the 600m/1.8km configurations is more accurate.

Annual volume ignores the timing of hypoxia but is sensitive to its duration+magnitude.

We expect the two model configurations to show substantial differences given the differences in the grid resolution, realism of physical circulation (salinity) and the distribution of terrestrial inputs.

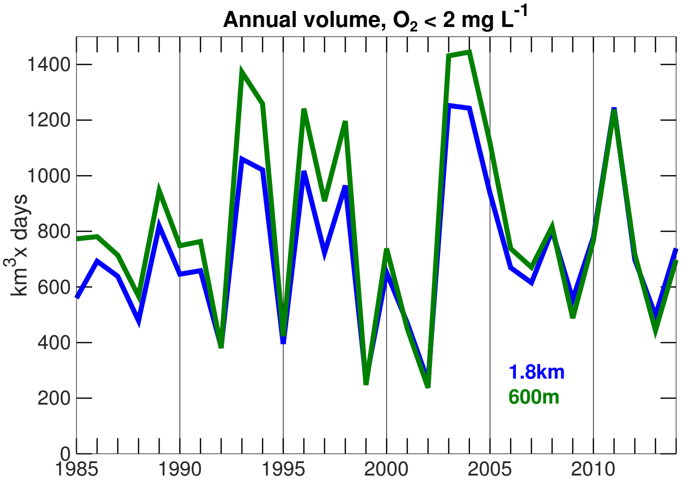


600m grid shows a significant improvement in the long-term averaged volume.

However, the two model configurations show nearly the same skill for the interannual variability (0.65 versus 0.63).

The two modeled curves are highly correlated together (0.97) despite differences in model configurations.

What about the other metric, annual hypoxic volume?



The two modeled curves are even closer in appearance, and highly correlated (0.97) together.

Key difference is that 600m values are slightly higher during years of high hypoxia.

(Same result for $O_2 < 1$ mg L^{-1}.)

Discussion

1. Similarities between results of 1.8km/600m grids suggest there are **external factors** driving the interannual variability and overshadowing differences between the two configurations.
2. (a) Nutrient availability. Empirical models of hypoxia, such as Scavia *et al*. 2006, have their interannual variability driven by riverine inputs of TN. They have substantial success in reproducing observed hypoxic volumes.

   Li *et al*. 2016 (GRL) also conclude that nutrient loadings drive interannual hypoxia in their 3-D model.
3. (b) Physical forcings (winds, temperature) may also drive the interannual variability, independently of nutrient availability. See Scully 2013, Hong & Shen 2013, Du & Shen 2015.
4. Both model configurations used the same hydrological and meteorological forcings, hence their similar year-to-year variability.
5. On smaller spatial/temporal scales, the 600m remains a major improvement, notably in tributaries like the Potomac.

Future work

We recently implemented a simple representation of phosphorus in the water column, based on Laurent *et al.* 2012.
The goal is to improve primary production in months when PO_4^{3-} is limiting. Terrestrial inputs are taken from Phase 6.

At the bottom, PO_4^{3-} is relaxed toward climatological concentrations from historical WQMP data. It mimics the net effect of all sediment-water PO_4^{3-} fluxes, without modeling them explicitly.

Phosphorus is not conserved with this approach (in contrast to N,C) but our goal is only to represent PO_4^{3-} limitation.